Utilizing Regionally Available Materials to Enhance Pavement Sub-Base Performance

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Abstract

The depletion of natural resources has become a significant concern in the construction sector, including the road construction segment. Extensive road construction activities demand vast quantities of aggregates, leading to considerable energy consumption through blasting, quarrying, crushing, and transportation. Moreover, the rapid depletion and shortage of aggregate materials have intensified the need for sustainable alternatives. Concurrently, industrial wastes, by-products, and locally available unused materials, often considered non-conventional, present environmental and disposal challenges but hold potential for road construction applications.

This study explores the utilization of two regionally available materials: slag, a waste product from the steel industry, and locally abundant gravel (moorum), in pavement sub-base layers. The research examines the chemical and phase composition, as well as the presence of toxic and heavy metals in both slag and its leachate water. Gradation and other physical properties are analyzed using appropriate tests and techniques. Conventional crushed aggregates are combined with slag or moorum to meet the required grading specifications of the Ministry of Road Transport and Highways.

The study identifies the optimal proportions of slag and moorum in the sub-base layer as 80% and 50%, respectively. Additionally, cement is used with moorum to achieve the desired strength. The physical properties of these materials indicate that both slag and hard moorum exhibit excellent characteristics for use as road aggregate, making them suitable for road base and sub-base applications.

Key words: Slag, Moorum, XRD analysis, Toxicity, Unconfined compressive strength, Sustainable construction, Aggregate alternatives.

1. Introduction

1.1 Background of the Study

Road transportation is a critical driver of economic, industrial, social, and cultural development in a country. India, possessing the second-largest road network globally, has seen significant advancements due to extensive road construction programs led by the Government of India. These initiatives, including the National Highways Development Programme (NHDP) and Pradhan Mantri Gramin Sadak Yojna (PMGSY), facilitate the construction of thousands of kilometers of roads annually, enhancing both urban and rural connectivity (Indian Highways, May 2011).

Pavement structures used in road construction are generally classified into two types: flexible and rigid. Flexible pavements consist of four main components: soil sub-grade, sub-base course, base course, and surface course. These components work together to transmit vertical loads from the top surface to the sub-grade. A well-compacted granular arrangement with well-graded aggregates forms a robust flexible pavement, efficiently distributing compressive stresses over a wider area. The base layer, positioned immediately below the surface layer, supports the pavement by transmitting loads to the underlying layers. The sub-base layer, situated below the base layer, provides additional support, transmits traffic loads to the sub-grade, and offers frost action and drainage capabilities. The sub-base generally consists of two layers: a lower filter layer, which prevents sub-grade soil intrusion, and an upper drainage layer composed of granular sub-base (GSB) materials to facilitate water drainage from surface cracks(Yoder & Witczak, Principles of Pavement Design).

Rigid pavements, in contrast, typically consist of a cement concrete slab, with a granular base or sub-base course beneath it. This base or sub-base course serves to manage drainage, control pumping, frost action, and mitigate shrink and swell of the sub-grade. Unlike flexible pavements, rigid pavements distribute loads differently; the critical condition arises from maximum flexural stress in the slab due to wheel loads and temperature changes, whereas flexible pavements distribute compressive stresses throughout the structure. Despite the notable flexural strength and rigidity of rigid pavements, flexible pavements are more commonly used due to their smoother riding surface and lower construction costs (Yoder & Witczak).

In light of the extensive demand for aggregates and the rapid depletion of natural resources, sustainable alternatives are imperative. Industrial wastes, by-products, and locally available unused materials, though often considered non-conventional, can address environmental and disposal challenges while holding potential for road construction applications. This study investigates the use of regionally available materials, specifically slag (a steel industry waste product) and gravel (moorum), in enhancing pavement sub-base performance. The research evaluates the chemical and physical properties of these materials and their potential for sustainable road construction.

1.2 Problem Statement

Traditionally, materials used in highway construction, such as sand, crushed aggregates, and gravels, are also employed in other construction activities, including buildings, industrial setups, dams, and powerhouses. These natural aggregate resources, essential for providing the necessary strength and durability in base and sub-base layers, are heavily consumed to meet the enormous demands of road construction, particularly in urban markets. The extraction of aggregates from hills through quarrying operations, crushing, and transportation not only contributes to environmental degradation—including the loss of forest lands, vibrations, dust, noise, and pollution hazards—but also consumes substantial amounts of energy, depleting our energy resources(Indian Highways, May 2011).

1.3 Objective

The present work focuses on the utilization of a combination of slag, locally available hard moorum, and conventional crushed aggregates of different nominal sizes for use in the base or sub-base layers of pavement. The objectives of this work are:

a) To determine the chemical composition, phase composition, and presence of hazardous materials in slag and its leachate water.
b) To evaluate the physical properties of slag and assess its suitability for use in the sub-base layer of pavement.
c) To examine the physical characteristics of locally available hard moorum and determine its suitability for use in the base or sub-base layer of pavement.
d) To investigate the effects of cement stabilization in base or sub-base layers incorporating natural aggregates and locally available gravel (hard moorum).
e) To explore the overall potential of utilizing regionally available materials to enhance the performance of pavement sub-base layers, thereby promoting sustainable road construction practices.

2. Literature Review

Basic oxygen furnace (BOF) slag as well as electric arc furnace (EAF) slag is also used for road base as well as road base asphalt concrete. In a trial, the mix design and performance characterization of the bituminous mixes was done in Italy. Gyratory compaction tests, indirect tensile strength tests, fatigue tests, permanent deformation tests and stiffness modulus tests (at various temperatures) of the mixtures of EAF slag and asphalt showed better mechanical characteristics than those of the conventional natural aggregate and asphalt mixture, satisfying the acceptable criteria for Italian road construction. **[Pasetto and Baldo (2010)]**.

In a moisture damage investigation of the road, the BOF prepared asphalt mixtures were characterised by resilient modulus tests, indirect tensile strength tests. The freeze-thaw tests showed better moisture sensitivity of BOF slag mixture than that of the basalt mixture **[Jun Xie., et al. (2012)]**.

The moorum collected from Sukrut (Uttar Pradesh) was mixed with Ganga sand and cement stabilised for use in Wet Mix Macadam (WMM) **[Ransinchung., et al. (2014)].** The physical properties of moorum, Ganga sand, crushed aggregate and stone dust were found out. The proportions of individual aggregates were determined so that the mixture would satisfy the desired gradation of MoRTH specifications. Ordinary Portland cement was used as a stabiliser and varying the cement content the CBR tests and the unconfined compressive strength tests were conducted. The results showed highest CBR value (423%) and unconfined compressive strength (18.55 kg/cm^2) at 9 percent cement content.

2.1 Critical Review

Various studies have demonstrated that steel slag can be effectively used as a material for road construction. Its physical and engineering properties have been found to be superior to those of natural aggregates. Characterization and leaching studies have confirmed that steel slag poses minimal hazardous effects on the environment, making it a viable option for unbound road pavements, provided it meets the necessary specifications and leachate water toxicity standards.

The application of hard moorum in road construction has been less extensively studied. However, available research suggests that moorum has potential for use in road base and sub-base layers. Given that the properties of moorum can vary significantly based on its geographical source, further studies are needed to generalize its properties and determine how effectively it can be utilized in road pavement applications.

This study aims to address these gaps by evaluating the use of steel slag and locally available hard moorum in road construction, focusing on their physical properties, environmental impact, and potential for enhancing pavement performance.

3. Experimental Methodology

Whether using natural aggregates, industrial wastes/by-products, or locally available materials, it is essential that these materials satisfy the desired physical properties and strength parameters for application in the base or sub-base layer of road pavement. Additionally, materials with the potential to affect the environment are subjected to chemical tests and characterization to ensure they are environmentally acceptable.

In this work, the chemical composition and characterization of slag were undertaken. The physical properties of slag, natural crushed aggregates, and moorum were determined according to relevant codes, specifications, and literature. The following test methods were carried out in this study:

- Chemical composition analysis to determine the elements present in slag and their concentrations.
- Phase composition analysis to identify the mineral phases in the slag.
- Hazardous materials assessment in slag and its leachate water to ensure environmental safety.
- Physical property tests for slag, natural crushed aggregates, and moorum, including:
- ✓ Gradation and particle size distribution
- ✓ Specific gravity and bulk density
- ✓ Moisture content and absorption
- ✓ Compaction characteristics (Proctor test)
- ✓ California Bearing Ratio (CBR) test for strength evaluation
- Cement stabilization effects on the mixture of natural aggregates and moorum to assess improvements in strength and durability.

These comprehensive tests ensure that the materials meet the necessary standards for use in road construction while promoting sustainable practices by utilizing locally available and industrial by-product materials.

3.1 Materials Used

The following materials were utilized for the study:

- **Slag**: Obtained as a waste material from the Rourkela Steel Plant premises.
- **Locally Available Hard Moorum**: Sourced from local regions for potential use in road construction.
- **Crushed Aggregates**: To be blended with slag or moorum to achieve the desired gradation, as per the

Ministry of Road Transport and Highways (MoRTH) specifications.

- **Cement**: Used as a binder for cement stabilization to enhance the strength and durability of the mixtures.
- **Chemicals**: Required for performing various chemical analyses to assess the properties and environmental impact of the materials.

These materials were selected to evaluate their effectiveness in road base and sub-base applications, with a focus on achieving desired performance standards and environmental safety.

4. Results and Discussion

4.1 Characterization of Slag

4.1.1 Chemical Composition

The chemical composition of the slag samples was determined by the XRF technique andis presented in table 4.1.

Table 4.1. Chemical Composition of the Slag Samples Determined By XRF Technique

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Chemical Composition	Percentage
SiO_2	27.33
FeO	20.91
Al_2O_3	6.03
CaO	31.03
MgO	9.24
MnO	4.50
S	0.10
TiO_2	0.66
K_2O	0.14

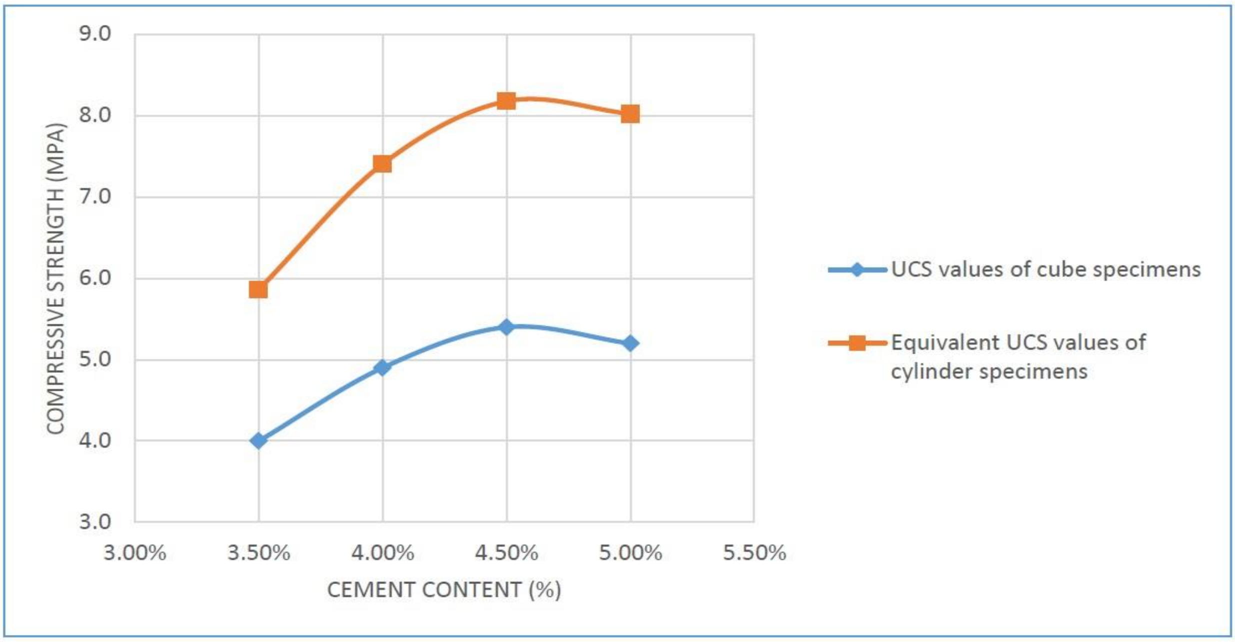

Figure 4.8 (b) Comparison of the UCS values of cube specimens with the equivalent UCSvalues of cylinder specimens for use in the cement treated base [Moorum=50%+ A10=15%+A6=35%]

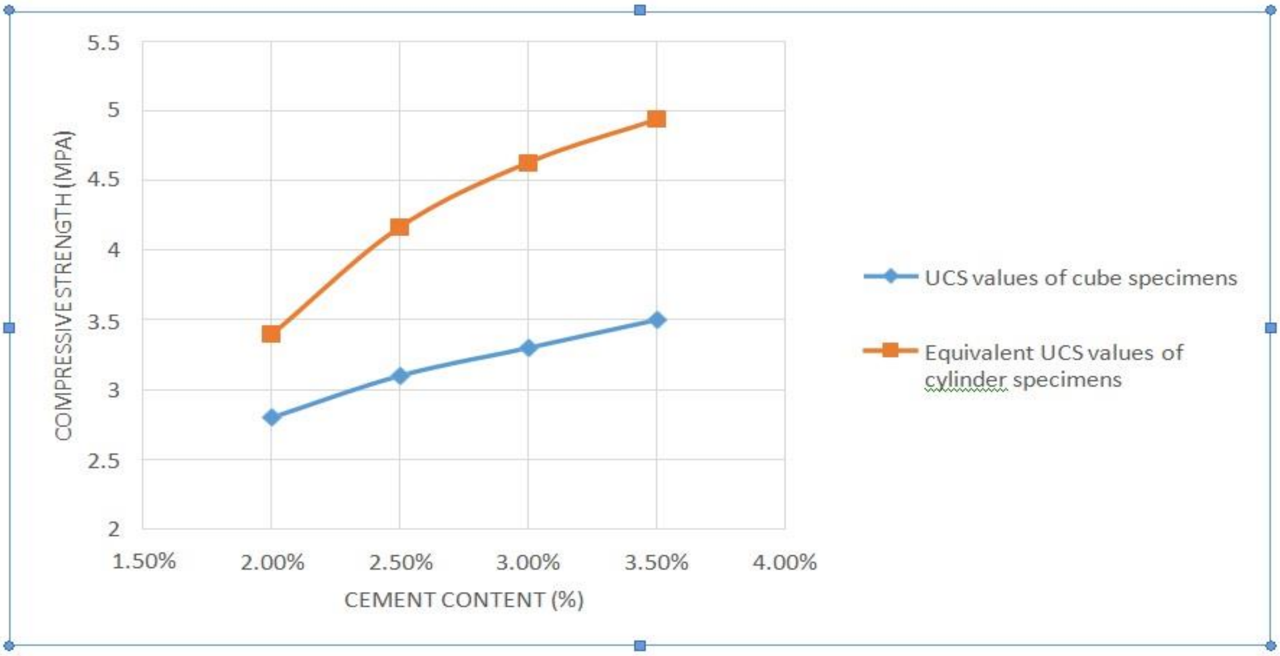

Figure 4.8 (C) Comparison Of UCS Values Of Cube Specimens With Equivalent UCS Values OfCylinder Specimens For Use In The Filter Layer Of Cement Treated Sub-Base [Moorum=50%+ A10=15% +A6=35%]

The UCS value of the combination of moorum and crushed aggregates was found to be more as compared to that of the combination of crushed aggregates only for particular cement content. The equivalent UCS values of the cylinder specimens were found to be more as compared to those of the cube specimens. The 7 days UCS values for cement bound materials should be between 4.5 to 7 MPa for use in the base and between 1.5 to 3 MPa for use in sub-base (drainage or filter layer) as per IRC SP: 89(2010). So depending on the required UCS value for construction of a particular layer the corresponding cement content can be taken to satisfy the requirements.

5. Conclusion and Future Scope

5.1 General

From the experiments conducted on the slag samples and locally available hard moorum, and from the analysis of results, the conclusions drawn are summarized below.

5.1.1 Characterization of Slag

The slag sample used in this work contains about 30% by weight of CaO, SiO2 and 20% by weight of FeO and some amount of Al2O3 and MgO, confirms the slag as steel slag.

The phases present in the slag are in carbonate, hydroxide or silicate form rather than oxide form making it suitable for construction purposes.

The heavy and toxic metals present in the slag and its leachate water are either zero or negligible. Hence, the potential for environmental hazards is very low.

5.1.2 Physical Properties

The slag samples are well graded which require less amount of crushed (conventional) aggregates for blending to meet the desired grading for use in different layers of sub-base. For filter layer a maximum up to 76% slag and for drainage layer a maximum up to 80% slag can be used to satisfy the desired grading (GSB grading II and grading IV respectively as per the MoRTH specifications).

- The finer material content in the moorum used for this work is very high. Hence, the amount of moorum that can be used for base and sub-base is limited to 50% in the total aggregate blend.

- The impact values of the slag, crushed aggregates and wet impact value of moorum are within the maximum limits for road base or sub-base applications.
- The specific gravity of the slag aggregates is much higher than that of the crushed aggregates. Hence, the MDD and CBR values of the slag and aggregate blends are very high.
- The specific gravity of moorum is comparatively more than that of the crushed aggregates. Hence, the MDD values are also higher in the moorum aggregate blend.
- Cement is used as a binder for stabilization of moorum because of its high plasticity (PI= 20). The UCS values of the combination of moorum and crushed aggregates specimens satisfy the desired lower limits for use in the cement treated base or sub-base layers.
- The UCS value of cement treated moorum-crushed aggregates blend is more as compared to that of crushed aggregates blend for particular cement content.

5.2 Conclusion

This study explored the use of slag and locally available hard moorum in various layers of road base and sub-base construction. The findings indicate the following key conclusions:

- ✓ **Slag Utilization:** The slag, sourced from the Rourkela Steel Plant, was found to be well-graded and suitable for use as a major aggregate component in road sub-base applications. It can constitute up to 80% of the total aggregate mix for both filter and drainage layers. The slag demonstrated excellent physical properties, meeting the required strength standards for road sub-base applications. Additionally, it was confirmed to be environmentally safe, showing no significant hazardous effects.
- ✓ **Hard Moorum Utilization:** The locally available hard moorum, characterized by a higher proportion of fine materials, is suitable for dense grading applications such as base or filter layers of the sub-base. It has the potential to replace conventional aggregates by up to 50% by weight. The physical properties of moorum met the desired requirements, and its strength can be enhanced by using a small amount of binder (cement). For specific binder content, moorum exhibited better strength than conventional crushed aggregates.

Overall, the study confirms that both slag and moorum can effectively replace traditional materials in road construction, offering sustainable alternatives that meet performance and environmental standards. The integration of these materials can contribute to more cost-effective and environmentally friendly road construction practices.

5.5 Future Scope of Work

The present study has provided valuable insights into the use of slag and locally available hard moorum in road construction. To further enhance the understanding and applicability of these materials, the following areas warrant additional investigation:

- ✓ **Dynamic Loading and Resilient Modulus:** While the study focused on strength parameters such as California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS), future research should include repeated load triaxial tests. These tests will help evaluate the effects of dynamic loading on different layers and determine the realistic resilient modulus values, which are crucial for assessing long-term performance under traffic loads.

- ✓ **Permeability Assessment:** The permeability of the slag and crushed aggregate mixture, particularly in the drainage layer of the sub-base, should be evaluated. Suitable tests can be conducted to measure the permeability of these materials, providing insights into their effectiveness in drainage applications and their potential impact on the overall pavement performance.

These additional studies will contribute to a more comprehensive understanding of the performance characteristics of slag and moorum in road construction and help optimize their use in various pavement layers.

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